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1. Your reference — CTV/P100850GB

2. Patent application number *(The Patent Office will fill in this part)* — 0218820.9 — 14 AUG 2002

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

antenova Limited
Far Field House
Bury Farm
Stoke-cum-Quy
CAMBRIDGE CB5 9AR

Patents ADP number *(if you know it)* 8306060001

If the applicant is a corporate body, give the country/state of its incorporation — UK

4. Title of the invention — An electrically small dielectric resonator antenna with wide bandwidth

5. Name of your agent *(if you have one)* — Harrison Goddard Foote

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Belgrave Hall
Belgrave Street
Leeds
LS2 8DD

Patents ADP number *(if you know it)* ~~14571001~~ 7631310002

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

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   a) any applicant named in part 3 is not an inventor, or
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Description	9
Claim *(s)*	0
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*		
Request for preliminary examination and search *(Patents Form 9/77)*		
Request for substantive examination *(Patents Form 10/77)*		
Any other documents *(please specify)*	1	Cover letter

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 14/8/2002

12. Name and daytime telephone number of person to contact in the United Kingdom Chris Vaughan 0113 233 0100

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AN ELECTRICALLY SMALL DIELECTRIC RESONATOR ANTENNA WITH WIDE BANDWIDTH

The present invention relates to a dielectric resonator antenna (DRA) having a feed and a groundplane having an aperture, the DRA having wide bandwidth.

Dielectric resonator antennas are resonant antenna devices that radiate or receive radio waves at a chosen frequency of transmission and reception, as used for example in mobile telecommunications. In general, a DRA consists of a volume of a dielectric material (the dielectric resonator) disposed on or close to a grounded substrate, with energy being transferred to and from the dielectric material by way of monopole probes inserted into the dielectric material or by way of monopole aperture feeds provided in the grounded substrate (an aperture feed is a discontinuity, generally rectangular in shape, although oval, oblong, trapezoidal 'H' shape, '<->' shape, or butterfly/bow tie shapes and combinations of these shapes may also be appropriate, provided in the grounded substrate where this is covered by the dielectric material. The aperture feed may be excited by a strip feed in the form of a microstrip transmission line, grounded or ungrounded coplanar transmission line, triplate, slotline or the like which is located on a side of the grounded substrate remote from the dielectric material). Direct connection to and excitation by a microstrip transmission line is also possible. Alternatively, dipole probes may be inserted into the dielectric material, in which case a grounded substrate may not be required. By providing multiple feeds and exciting these sequentially or in various combinations, a continuously or incrementally steerable beam or beams may be formed, as discussed for example in the present applicant's co-pending US patent application serial number US 09/431,548 and the publication by KINGSLEY, S.P. and O'KEEFE, S.G., "Beam steering and monopulse processing of probe-fed dielectric resonator antennas", IEE Proceedings - Radar Sonar and Navigation, 146, 3, 121 - 125, 1999, the full contents of which are hereby incorporated into the present application by reference.

The resonant characteristics of a DRA depend, *inter alia*, upon the shape and size of the volume of dielectric material and also on the shape, size and position of the feeds thereto. It is to be appreciated that in a DRA, it is the dielectric material that resonates when excited by the feed. This is to be contrasted with a dielectrically loaded antenna, in which a traditional conductive radiating element is encased in a dielectric material that modifies the resonance characteristics of the radiating element.

DRAs may take various forms, a common form having a cylindrical shape which may be fed by a metallic probe within the cylinder. Such a cylindrical resonating medium can be made from several candidate materials including ceramic dielectrics.

Since the first systematic study of dielectric resonator antennas (DRAs) in 1983 [LONG, S.A., McALLISTER, M.W., and SHEN, L.C.: "The Resonant Cylindrical Dielectric Cavity Antenna", IEEE Transactions on Antennas and Propagation, AP-31, 1983, pp 406-412], interest has grown in their radiation patterns because of their high radiation efficiency, good match to most commonly used transmission lines and small physical size [MONGIA, R.K. and BHARTIA, P.: "Dielectric Resonator Antennas - A Review and General Design Relations for Resonant Frequency and Bandwidth", International Journal of Microwave and Millimetre-Wave Computer-Aided Engineering, 1994, 4, (3), pp 230-247]. A summary of some more recent developments can be found in PETOSA, A., ITTIPIBOON, A., ANTAR, Y.M.M., ROSCOE, D., and CUHACI, M.: "Recent advances in Dielectric-Resonator Antenna Technology", IEEE Antennas and Propagation Magazine, 1998, 40, (3), pp 35 - 48.

A variety of basic shapes have been found to act as good DRA resonator structures when mounted on or close to a ground plane (grounded substrate) and excited by an appropriate method. Perhaps the best known of these geometries are:

Rectangle [McALLISTER, M.W., LONG, S.A. and CONWAY G.L.: "Rectangular Dielectric Resonator Antenna", Electronics Letters, 1983, 19, (6), pp 218-219].

Triangle [ITTIPIBOON, A., MONGIA, R.K., ANTAR, Y.M.M., BHARTIA, P. and CUHACI, M.: "Aperture Fed Rectangular and Triangular Dielectric Resonators for use as Magnetic Dipole Antennas", Electronics Letters, 1993, 29, (23), pp 2001-2002].

Hemisphere [LEUNG, K.W.: "Simple results for conformal-strip excited hemispherical dielectric resonator antenna", Electronics Letters, 2000, 36, (11)].

Cylinder [LONG, S.A., McALLISTER, M.W., and SHEN, L.C.: "The Resonant Cylindrical Dielectric Cavity Antenna", IEEE Transactions on Antennas and Propagation, AP-31, 1983, pp 406-412].

Half-split cylinder (half a cylinder mounted vertically on a ground plane) [MONGIA, R.K., ITTIPIBOON, A., ANTAR, Y.M.M., BHARTIA, P. and CUHACI, M: "A Half-Split Cylindrical Dielectric Resonator Antenna Using Slot-Coupling", IEEE Microwave and guided Wave Letters, 1993, Vol. 3, No. 2, pp 38-39].

Some of these antenna designs have also been divided into sectors. For example, a cylindrical DRA can be halved [TAM, M.T.K. and MURCH, R.D.: "Half volume dielectric resonator antenna designs", Electronics Letters, 1997, 33, (23), pp 1914 - 1916]. However, dividing an antenna in half, or sectorising it further, does not change the basic geometry from cylindrical, rectangular, etc.

According to a first aspect of the present invention, there is provided a dielectric resonator antenna comprising a dielectric resonator mounted on a first side of a dielectric substrate, a microstrip feed located on the first side of the substrate and extending between the substrate and the dielectric resonator, and a conductive layer

formed on a second side of the substrate opposed to the first, wherein an aperture is formed in the conductive layer at a location corresponding to that of the dielectric resonator.

Embodiments of the present invention are electrically small, have wide bandwidth and good gain characteristics, are efficient and are not easily detuned.

Embodiments of the present invention are particularly well suited as mobile telephone handset antennas, where increasingly wide bandwidths are required to cover the extra functionality that modern handsets need for operations at 3G (third generation) and Bluetooth® bands as well as existing GSM bands.

The conductive layer on the second side of the substrate acts as a groundplane for the antenna of the present invention..

The aperture in the conductive layer is preferably greater in area than a surface of the dielectric resonator that contacts the first side of the substrate. The aperture may be rectangular in shape or any other appropriate shape. The aperture may have a similar or substantially identical shape to that of the surface of the dielectric resonator that contacts the first side of the substrate, or may have a different shape.

The dielectric resonator may be a piece of low-loss dielectric ceramics material, and is preferably oblong or rectangular in shape, a half-split cylinder, or a half-split cylinder with its curved surface ground down so as to be substantially flattened. Other shapes and configurations are not excluded. It has been found that embodiments of the present invention work well with different dielectric ceramics materials having different dielectric constants.

The microstrip feed advantageously passes between the dielectric resonator and the first side of the substrate at or towards one end of the dielectric resonator. Preferably, the microstrip feed has a substantially linear extension in a vicinity of the dielectric

resonator, the substantially linear extension being disposed substantially orthogonal to a major axis of the dielectric resonator.

The microstrip feed line may extend only part way across a width of the dielectric resonator, or may extend across a full width of the dielectric resonator, or may even extend beyond a full width of the dielectric resonator. Although the best performance from the antenna of embodiments of the present invention has been observed when the microstrip feed is disposed as described above, it has been found by experimentation that other feed shapes do work, including feeds that bend or curl round under the dielectric resonator, or are 'L' shaped, 'U' shaped, etc. under the dielectric resonator and are not orthogonal to the major axis of the dielectric resonator at every point.

The aperture in the conductive layer need not be surrounded on all sides by conductive material. For example, the aperture may be formed at an edge or corner of a substrate or may extend across a full width of a substrate. However, it is generally preferred for the aperture to be surrounded on all sides by conductive material.

It has been found that for any particular shape or configuration of dielectric resonator, there is an optimum or near-optimum size for the aperture.

Increasing a width of the slot (i.e. in a direction of extension of the microstrip feed) tends to increase the bandwidth of the DRA.

Increasing a length of the slot (i.e. in a direction generally orthogonal to the extension of the microstrip feed) tends to improve a frequency match, but does raise the resonant frequency of the DRA.

The present applicant has found that the presence of the aperture in the conductive layer is crucial for exceptionally wide bandwidth performance. However, it has been

found by experimentation that part of the aperture can be 'filled in' by conducting material on either or both surfaces, provided that such conducting material does not touch the main groundplane. Further, when the aperture runs across a top edge of the substrate so that it has only one boundary with the main groundplane and when the aperture is filled in with conducting material on the same side as the groundplane with just a small gap between the two, then the width of the gap is crucial to obtaining a good return loss (a good match to 50 ohms). The return loss is poor for a gap of 0.5 mm, fair for a gap of 2 mm and good for a gap greater than 5 mm.

Prototypes of embodiments of the present invention have been constructed using a printed circuit board substrate material as the dielectric substrate, and copper as the conductive layer. It will be clear that other materials with appropriate characteristics may be used. It has been found that the antenna of embodiments of the present invention works well for different types of substrates having different thicknesses and different dielectric constants.

It has also been found that the dielectric resonator can be placed on the second surface of the substrate, i.e. on the same side as the aperture. In this configuration it is more like conventional slot feeding, but with a much larger slot or aperture than is customarily used.

According to a second aspect of the present invention, there is provided a dielectric resonator antenna comprising a microstrip feed located on a first side of a dielectric substrate, a conductive layer formed on a second side of the substrate opposed to the first and having an aperture formed therein; wherein a dielectric resonator is mounted on a second side of the substrate within or at least overlapping the aperture.For a better understanding of the present invention and to show how it may be carried into effect, reference shall now be made by way of example to the accompanying drawings, in which:

FIGURE 1 is a schematic plan view of a first embodiment of the present invention;

FIGURE 2 is a perspective view of the embodiment of Figure 1;

FIGURE 3 is a plan view of a second embodiment of the present invention;

FIGURE 4 is a plot of a vertical elevation radiation pattern for the embodiment of Figure 1;

FIGURE 5 is a plot of a horizontal elevation radiation pattern for the embodiment of Figure 1;

FIGURE 6 is a plot of an azimuth radiation pattern for the embodiment of Figure 1; and

FIGURE 7 shows a computer-simulated 3D radiation pattern for a third embodiment of the present invention, also shown in Figure 7.

Referring to Figure 1, there is shown a dielectric substrate 1 in the form of a PCB, on a first surface of which is mounted a low-loss dielectric ceramics pellet 2 formed as a half-split cylinder with its curved face ground down to leave a flat top surface. A microstrip feed line 3 extends across the first surface of the substrate 1 from an SMA connector 4 and passes between the pellet 2 and the first surface of the substrate 1. It can be seen that the microstrip feed line 3 is substantially orthogonal to a major axis of the pellet 2 and passes thereunder at one end thereof. A second surface of the substrate 1, opposed to the first surface, is provided with a conductive metal layer 5, except in a region underneath the pellet 2 where an aperture 6 is defined by an absence of conductive material 5.

A prototype DRA has been constructed with a pellet 2 having a length of 18.2mm, a height of 5.8mm and a width of 8mm; the pellet 2 being mounted on a PCB 1 having a length of 80mm, a width of 35mm and a thickness (depth) of 1.6mm. A layer of

copper has been used as the conductive layer 5. In one embodiment, the aperture 6 has a length of 35mm (corresponding to the width of the PCB 1) and a width of 14mm; in another embodiment, the aperture 6 has a length of 35mm and a width of 13.5mm.

Typical performance figures for the prototype DRA described above are shown in Table 1:

Table 1

	Min Frequency	Centre Frequency	Max Frequency	Measurement Level	Bandwidth %	Gain
S11	1444 MHz	2062 MHz	2230 MHz	VSWR 3:1	38%	N/A
S21	1250 MHz	1790 MHz	2330 MHz	-3dB	60%	3.3 dBi

The results show that the S_{11} return loss bandwidth and the S_{21} transmission bandwidth are both remarkably large for such a small antenna having good gain (3.3dBi).

Figure 2 shows an alternative view of the embodiment of Figure 1, with like parts being labelled as in Figure 1. The flattened top surface 7 of the pellet 2 is clearly shown.

Figure 3 shows an alternative embodiment of the present invention where the aperture 6 extends across a whole width of the substrate 1.

Figures 4, 5 and 6 respectively show vertical elevation, horizontal elevation and azimuth radiation patterns for the embodiment of Figure 1 at various frequencies. It can be seen that useful gain is obtained across a frequency band from 1710 to 2170MHz. This frequency band encompasses the European 1800MHz, US 1900MHz and WCDMA mobile telephone frequency bands.

The DRA of the present invention has been simulated using Ansoft® HFSS electromagnetic simulation software. The simulation confirms that the DRA radiates effectively over a wide bandwidth and that the results are not merely a measurement artefact arising due to radiation from cables, microstrips and the like. Figure 7 shows a simulation of a 3D radiation pattern at 1940MHz, which is in general agreement with measured patterns at that frequency. Figure 7 also shows a schematic of the simulated DRA, with parts being labelled as in Figure 1.

The preferred features of the invention are applicable to all aspects of the invention and may be used in any possible combination.

Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of the words, for example "comprising" and "comprises", mean "including but not limited to", and are not intended to (and do not) exclude other components, integers, moieties, additives or steps.

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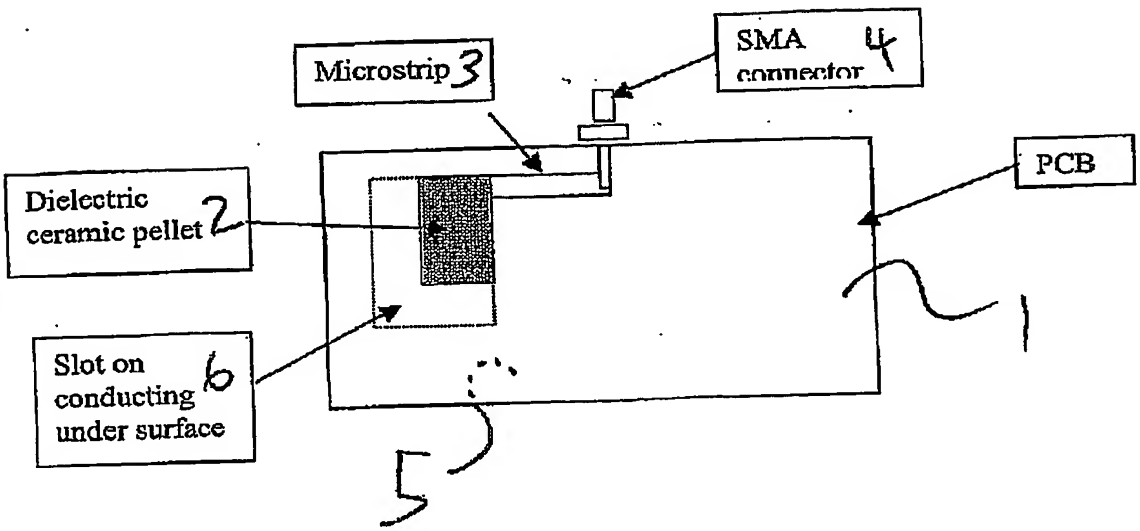

Figure 1. Basic design of the antenna

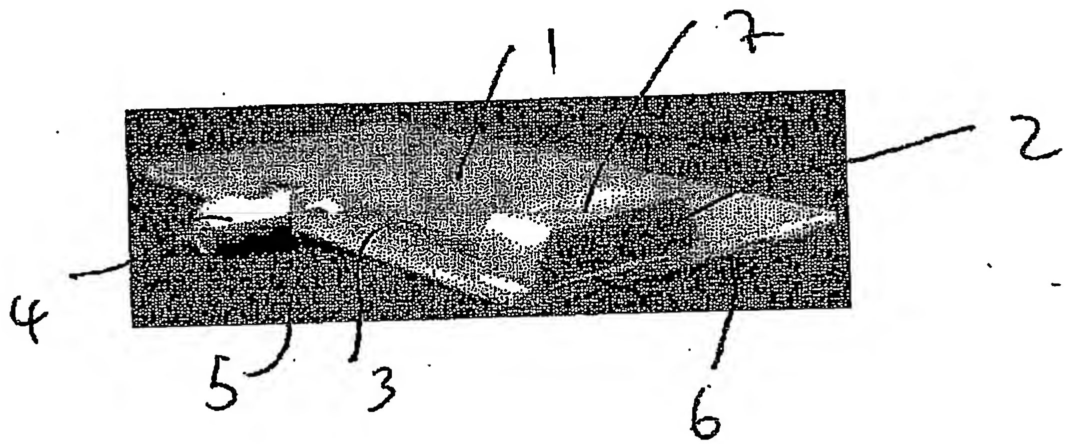

Figure 2. Photograph of a prototype antenna showing dielectric ceramic pellet attached to a microstrip feed on the upper surface of the substrate.

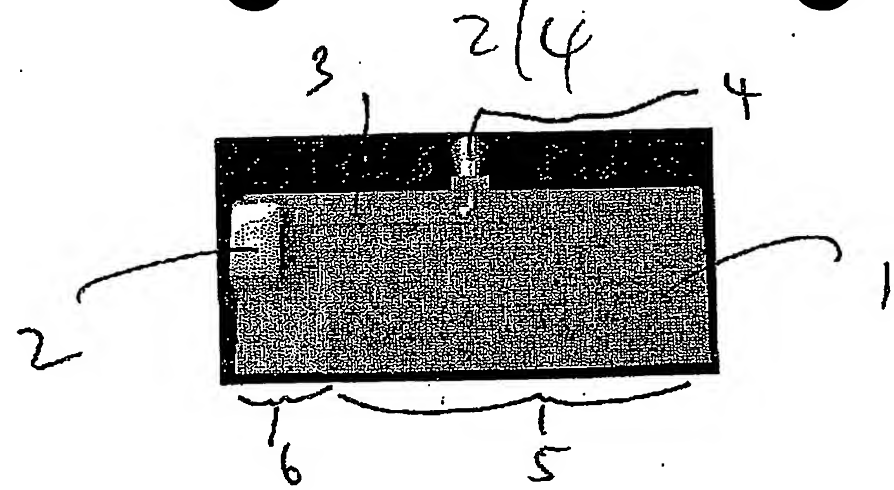

Figure 3. Photograph of a prototype antenna showing how the slot can be extended across the full width of the board.

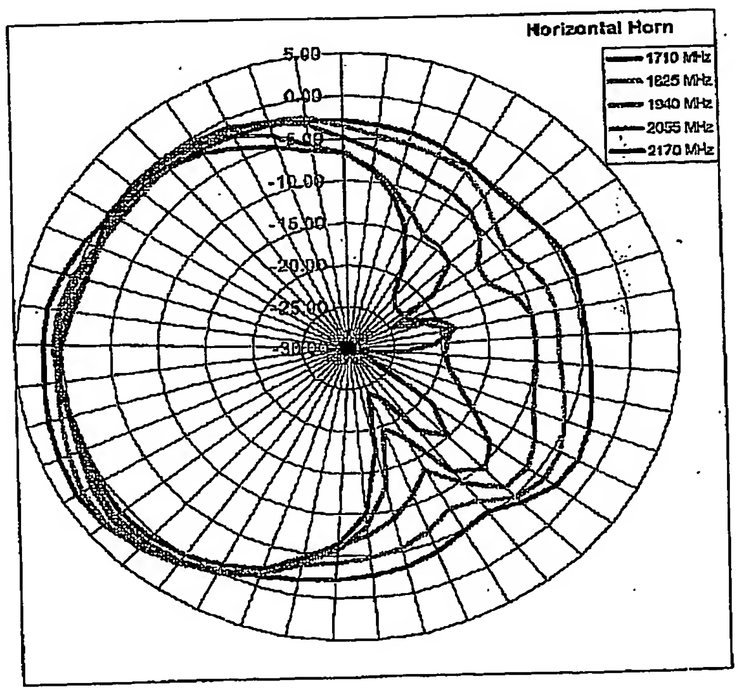

Figure 4. Vertical elevation pattern

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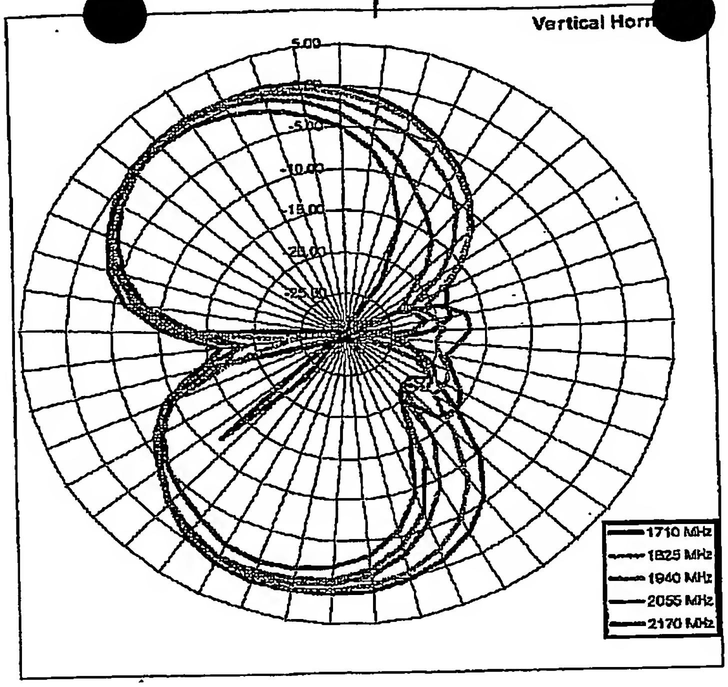

Figure 5. Horizontal elevation pattern

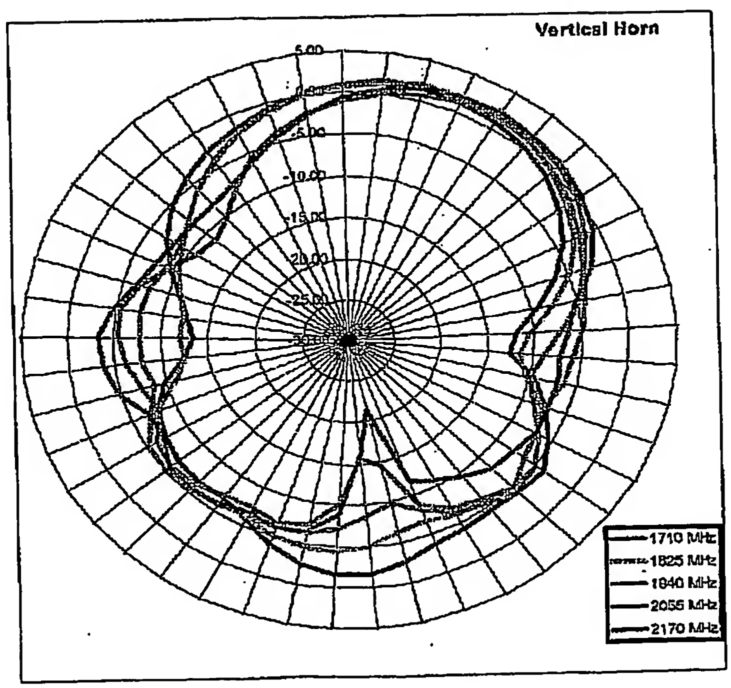

Figure 6. Azimuth pattern

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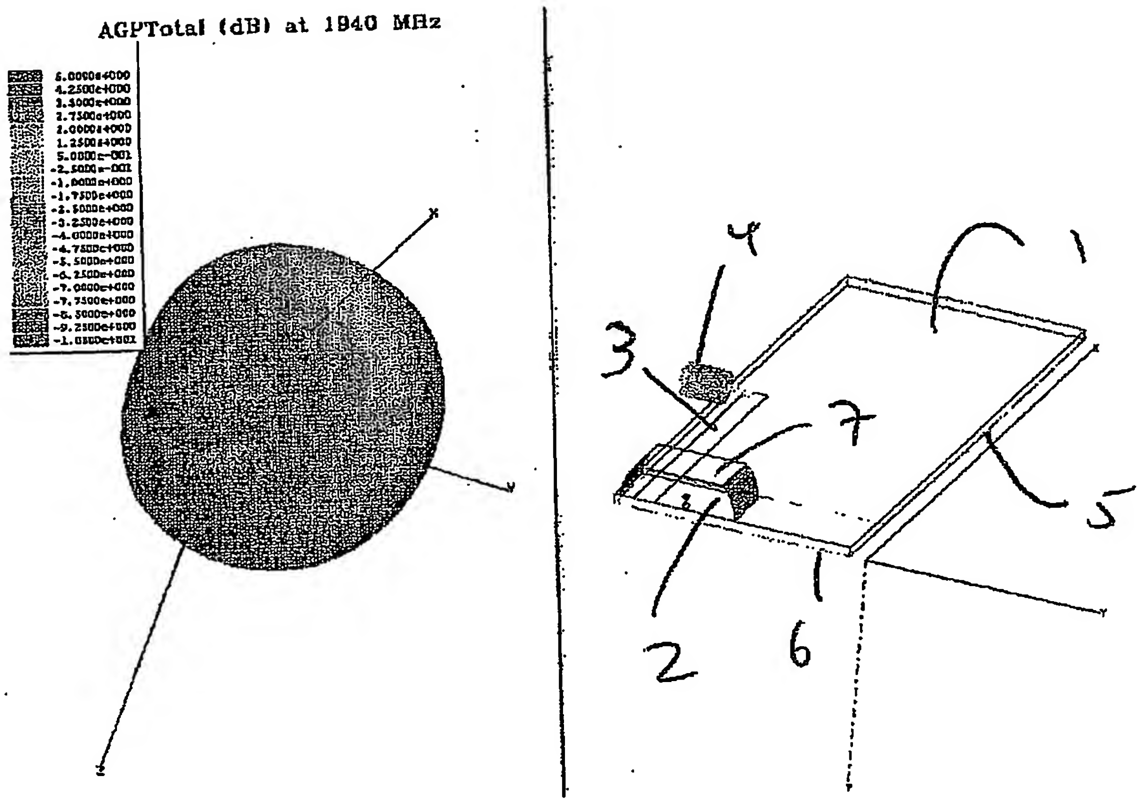

Figure 7. Computer simulation of the 3-D radiation pattern at 1940 MHz.

PCT Application
GB0303546